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Development and Testing of a Non-Recording Microdensitometer

Charles Biss

Randy DeFrank

DEVELOPMENT AND TESTING OF A NON-RECORDING MICRODENSITOMETER

by

Charles E. Biss
Randy DeFrank

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in the School of Photographic Sciences in the College of Graphic Arts and Photography of the Rochester Institute of Technology

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Thesis advisers: Frank A. Cicha
Professor Hollis N. Todd

ABSTRACT

A need exists in American industry for a small-area reading densitometer. The object of this effort was to examine optical designs proposed by Photographic Sciences Corporation, to formulate a reasonable system design, and to work this design into a prototype instrument.

After testing several optical designs, one was chosen that proved its feasibility on the micro-optical bench. A case was designed for the unit and the optical system made of microscope components was set into place.

A photomultiplier tube and amplifier were incorporated as the photometric measuring device.

The system was tested and proved to exhibit the qualities of a compact, non-recording, small-area densitometer.

INTRODUCTION

A major densitometer manufacturer in the United States conducted a survey in the past three years on the marketability of a compact and inexpensive small-area densitometer. Evaluation of this survey indicated that first year sales would reach approximately ten thousand units and that sales in the next five years would be close to two thousand per year. These results indicate a desire in the American photographic industry for such an instrument.

Equipment presently available in this area is large, expensive, and/or needs specially trained personnel for proper maintenance.

Preliminary research into the feasibility and design of a small-reading area densitometer was done in the past three years by Mr. John E. Blackert of Photographic Sciences Corporation. The outcome of his work produced many feasible designs for an instrument of this type.

These designs were utilized in the research work done. Primary use of the prototype would be as a transmission densitometer in the graphic arts industry.

DESIGN PARAMETERS

Originally certain design parameters were set down for the unit. As the project progressed, the shortcomings of some of these parameters were realized, and they were changed accordingly. Following are the original parameters and the changes made:

A photometric measuring unit, a photomultiplier tube and amplifier, must have a density reading range of 0.00 to 1.50 as the minimum. (Graphic arts printing density of a dot or line must be approximately 1.00.) This parameter was kept and achieved in the testing and construction of a unit.

The system was to incorporate standard microscope parts. This will allow easy modification of the system for magnification, effective aperature, and sensor placement changes.

A reflex viewing screen was to be utilized in order to allow for easy location of the area to be read and to insure that the area desired is being read. This will be brought about by having the operator place or align the object to be read under the reading dot. Modification of the original mirror and mounting bracket was necessary to achieve this.

The light source of the unit was to be constructed using components from a commercial densitometer in conjunction with microscope optics for focusing.

The system was to be a specular or "semi" specular reading unit.

The packaging of the system should give a prototype unit approximately the size of a standard desk top macro-densitometer, i.e. MacBeth TD-102.

EXPERIMENTATION

Initial work on the optical design proceded along the lines of work done by John E. Blackert of Photographic Sciences Corporation. From Mr. Blackert's work, a particular design was devised which showed desirable operating characteristics.

This design had these characteristics: a viewing screen would be incorporated in order to allow the operator to view a large portion of the sample; a dot on the screen would be aligned with the area to be read; the system would be adaptable to many sample thicknesses due to refocusing; and effective aperature would be variable through changes in objectives.

The system was made up of standard microscope components. The choice of microscope optics was primarily due to cost and easy accessibility of these parts. One objective of the project was to prepare a prototype using low cost parts of easy availability.

This primary design, found in Appendix A, was assembled on the micro optical bench as a macro-density unit without the reflex mirror in position. This system proved to function properly. A magnified image of the sample was found.

The light source used was taken from a Welsh Densichron Transmission Light Unit #3853A. This light system is a complete unit. It is supplied with a condensor system which corrects for visual density readings, since this unit was designed for graphic arts usage and will be used for reading black and white materials.

The stage area is a 4 X 6 white acrylic surface with a 1.27 mm physical aperture added. This aperture is one supplied by Welch with their units. The aperture is normally specified as being 1 mm, but measuremênts show discrepancies in the actual sizes. This aperture is large enough to permit viewing of a larger area than is read, but small enough to aid in the prevention of flare in the system.

The original light system used two sets of condensor lenses. For this system one condensor is fixed to the back of the stage area below the aperture. The second condensor is moveable for alignment and focus. The method for focusing the system was to hold a piece of paper firmly over the aperture and to move the condensor up and down until this maximum intensity was obtained. The circle of light produced by the aperture was sharp on the paper. The lamp position was readjusted to give maximum intensity and uniformity on the projection.

The objective chosen for this project is the Bausch and Lomb objective from the achromatic series. It is a 10x objective, dry achromatic, divisible lens (catalog number 31-10-22-01). This lens has a numerical aperture of 0.25, effective focal length of 16 mm and has a working distance of 4.5 mm. The lens is balcoted (anti-reflection coating on surface). This lens gave adequate magnification of a 20% eliptical half-tone dot. At this magnification adequate energy was present at the photomultiplier tube to yield a density reading. Manipulation of the sensitivity in the electronics of the photomultiplier tube amplifier could be done to give an extended range. The fact that the lens is divisible makes it very versatile. With the lower portion of the objective removed the lens becomes a 4x objective. This allows for readings to be taken on larger size objects without a large drop in the illumination. The unit approaches a standard densitometer system at this magnification.

The eyepiece for the microscope portion of the system is taken from a Nikon Binocular microscope system. This lens is a 10x coated lens with a focal length of 25 mm. The Nikon H.K.W. 10x eyepiece is taken from the Microscope Conversion Kit #811.

The projection hood used is a Nikon unit. It contains a 45° angle reflex mirror, front surface coated, and an eyepiece for the system. The image is projected onto a diffuse glass screen (screen size: $3\frac{1}{2}$ inches in diameter). The inside of the hood and mirror mounting bracket are flat black to prevent reflections. The hood is mounted to a microscope system using an S.D25 Nikon bracket.

To accommodate the optical design, a special mirror was ordered with an aperture etched in the surface. The mirror is a 3 mm thick front surface chromed mirror with a 2.8 mm aperture etched in the coating. The aperture is clear; the mirror is polished on both sides. The mounting bracket for the mirror from the Nikon hood is drilled out and blackened to allow a path for the transmitted light to pass to the image plane where the sensor is placed.

The hood eyepiece has a focal length of 170 mm. With the addition of the mirror to the system there was 80 mm distance between the base of the mirror and the eyepiece. The total distance in the hood is 162 mm from the eyepiece to the image plane. It is 82 mm to the front of the screen from the base of the mirror. The screen is approximately 3 mm thick. With the mirror in place the projected aperture (area that is to be read and seen) is 6.35 mm. The hood is cut open on the top to permit work to be done behind the mirror. Using a thin diffuse plastic slide, the image plane is checked with and without the mirror. The position does not change.

In the initial design of this system and at other times after this, various designs have been proposed by faculty and students of Rochester Institute of Technology to us. One particular change in design was to reposition the mirror into the image plane as either a 45° angle mirror or parallel to the image plane. The sensor would be placed directly in the image plane as before. These two systems eliminate the screen, force the operator to view off the mirror, which is now in a very high position. The projected image is also out of focus on the edges of the mirror. When the mirror is tilted 45°, this causes focus problems for the operator.

At one point it was felt that the projected image through the aperture would not be intense enough to enable a density reading to be made. This idea was caused by the fact that a projected image could not be focused in the image plane. Experimentation with the addition of lenses behind the mirror and below came up with a new design. A convex lens of focal length 64.77 mm could be added on top of the hood eyepiece system. This would drop the eyepiece system focal length to 40 mm. This also reduces the projected image so that it no longer fills the projection screen. It was finally decided to check the optical alignment of the system. After adjustments are made of the light source optics and the mirror, the image is focused in the image plane.

The final design uses two optical systems: the microscope system and the projection hood system.

The microscope system has a distance of 160 mm between the ocular and the objective. The distance between the hood ocular and microscope ocular is 25 mm. The hood measures 162 mm from the ocular to the image plane.

The photomultiplier tube was placed behind the mirror in the focused image plane. Visual checks of the reading dot were made both at the placement of the sensor and at the viewing screen. These both showed a dot in focus and of the same size. From this the conclusion was drawn that the dot seen on the screen is the area being read by the sensor.

The reading dot as seen on the viewing screen is seen as being off center in respect to the center of the screen. This is due to incorrect measurements in the etching of the mirror. However, with the mirror and optics aligned as in the unit this positioning problem does not affect the density reading capabilities. The only affect it has is in the appearance of the viewing screen.

The decision to design a new case stemmed mainly from the flimsy construction and lack of internal space of the original transmission unit.

The case was constructed of aluminum plate. All sides with the exception of the top and control panel were 1/4 inch thick. The control panel is 1/8 inch to assure easy mounting of controls. The top panel was made of 1/2 inch thick plate. One of the problems was that of rigidity of the reading--viewing optics system and resultant vibration of the system if rigidity was not obtained. It was found that if the optics mounting post was secured through the 1/2 inch plate vibration was minimized.

The decision was made to mount all optics and light source parts to both the top and bottom of the 1/2 inch plate to insure constant alignment of these parts after continuous dis- and re-assembly.

The case was increased by one inch in all dimensions to insure adequate room inside for possible modificiation of the layout of the electronics.

The case pieces were black anodized with the exception of the control panel which was clear anodized.

A sketch of the final unit's case and case component drawings can be found in Appendix B.

The power system for the light source and stage lights was taken from the original transmission light box and moved directly into the new case.

The first photometric measuring device used was a Welch Densichron Model 1 Photometer with a Model 3830A Amplifier. This unit is used in the initial testing of the optics system.

The amplifier is a relatively small vacuum tube unit and could be easily modified to make a more compact unit.

After being contacted by Frank A. Cicha, the project adviser at Photographic Sciences Corporation, it was brought to our attention that we could obtain a Welch Digital Readout Densitometer Model 3843A. This unit has solid state components with a digital nixie tube readout.

It was felt that this equipment would be more adaptable with its digital readout from a marketing standpoint, more desirable in industry.

The amplifier and transmission probe has a readable density range from 0.00 to 3.00. This greatly surpasses our needs. The transmission probe incorporates a push to read switch and a fiber optics bundle to direct light to the RCA 321 A photomultiplier tube mounted in the amplifier chassis.

Another feature of the Welch Digital Unit is a BCD output to be used in incorporation with a computer-type punch.

The digital unit was disassembled and removed from its original chassis. All wiring was marked for re-assembly. The major components were mounted in the new case and wiring to these components completed. The wiring was found to be quite difficult due to component location and design deficiencies in the original circuit wiring.

The push to read switch along with switching for the stage lights was connected to a relay activated by a foot switch.

It was also necessary to build a light tight compartment for the photomultiplier tube and mount that in the case.

After installation and final wiring check out, power was applied to the unit and it was found that the unit was operating, but it was doing so erratically. After a short period the unit ceased to function for a yet undetermined reason.

In order to continue and finalize testing of the unit, the Welch Model 1 Photometer was incorporated into the system to replace the digital electronics. This was found to be satisfactory.

After final assembly the unit was checked to determine operating abilities.

A calibrated step tablet was supplied by Photographic Sciences Corporation and used to make density reading tests. A 1/16 inch sheet of clear plexiglass with a 1/16 inch diameter hole in the middle was incorporated to insure the sample read would lie flat in the illuminated aperture plane.

Proper alignment and illumination of the screen and optical system was checked and density measurements were proceeded with.

By using the Rochester Institute of Technology micrometric scale, which is supplied with the Rochester Institute of Technology Alpha-numeric test target, the effective aperture and area read was measured at 40 micrometers.

It should be noted that a system of this type is "semi"-specular. The cone angle of the viewing system is 0^{o} while the light source has an unknown cone angle. To test this system, a calibrated step tablet is used to relate a diffuse density value of the step tablet to the microdensitometer reading. If the readings vs. diffuse density values have a slope of 1, the microdensitometer will be yielding diffuse density. A unit that is partly specular will give a plot that has a higher slope. This also checks the system for flare. A system with optical problems such as flare would yield a curve other than a straight line function.

In checking this system, it was found that a higher slope was obtained (slope = 1.25). This shows that this system is partially specular and does not have a problem with flare (for data, see Appendix C). This means that this system yields a relative density value. For various material types, calibration curves may be made to relate the readings to an absolute density value, if this is needed. For most graphic arts work, this is unnecessary. A relative value can be used. For one particular material such a Kodalith Type 3 Ortho 6556, a 20% eliptical dot of microdensity reading of 0.95 or higher would be a "no-print" condition for some offset plates.

The optical system when tighted down will stay in focus for at least two days when one particular thickness of material is used. It should be noted that refocusing of different materials should be done. If a step tablet is used, the edge of a step can be used to determine if it is in focus. "Knocking" the unit around the microscope unit does not change the position of the image or the focus.

CONCLUSIONS

Based on the test data the system is stable and useable. It does not exhibit problems of flare and proves to be slightly specular. (This rules out Callier's Q being used, because the Q-Factor is for only totally specular systems.) Relative density units are useable; but in cases where absolute density units are needed, a calibration curve can be made. The final unit can easily read from 0.00 to 1.50 on the Welsh meter and is sensitive enough to read over two scales. For this work, only one scale was used and data obtained over only one scale. It is, therefore, possible with changes in the unit sensitivity (internal) that a higher sensitivity can be read if needed.

(See Appendix D for suggestions for modification and further investigation.)

Acknowledgments

We would like to thank the following persons for their much appreciated assistance in this research project:

Photographic Sciences Corporation, Webster, New York, for it's sponsorship of this project.

John E. Blackert, President, Photographic Sciences Corporation

Frank A. Cicha, Thesis Advisor, Marketing Manager, Photographic Sciences Corp.

Prof. Hollis N. Todd, Thesis Advisor, Rochester Institute of Technology

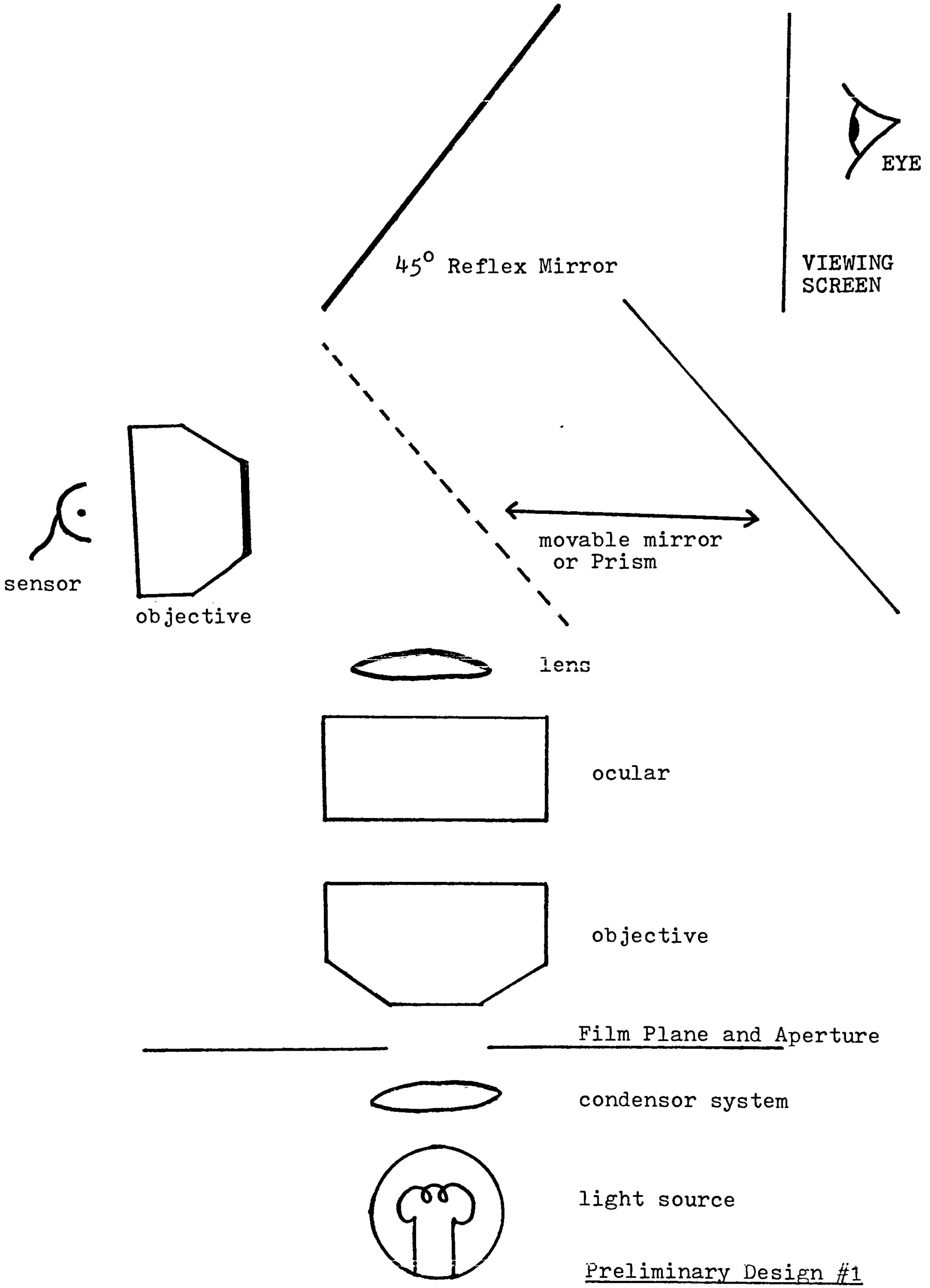
Dr. G. W. Schumann, Rochester Insitute of Technology

Richard Norman, Rochester Institute of Technology

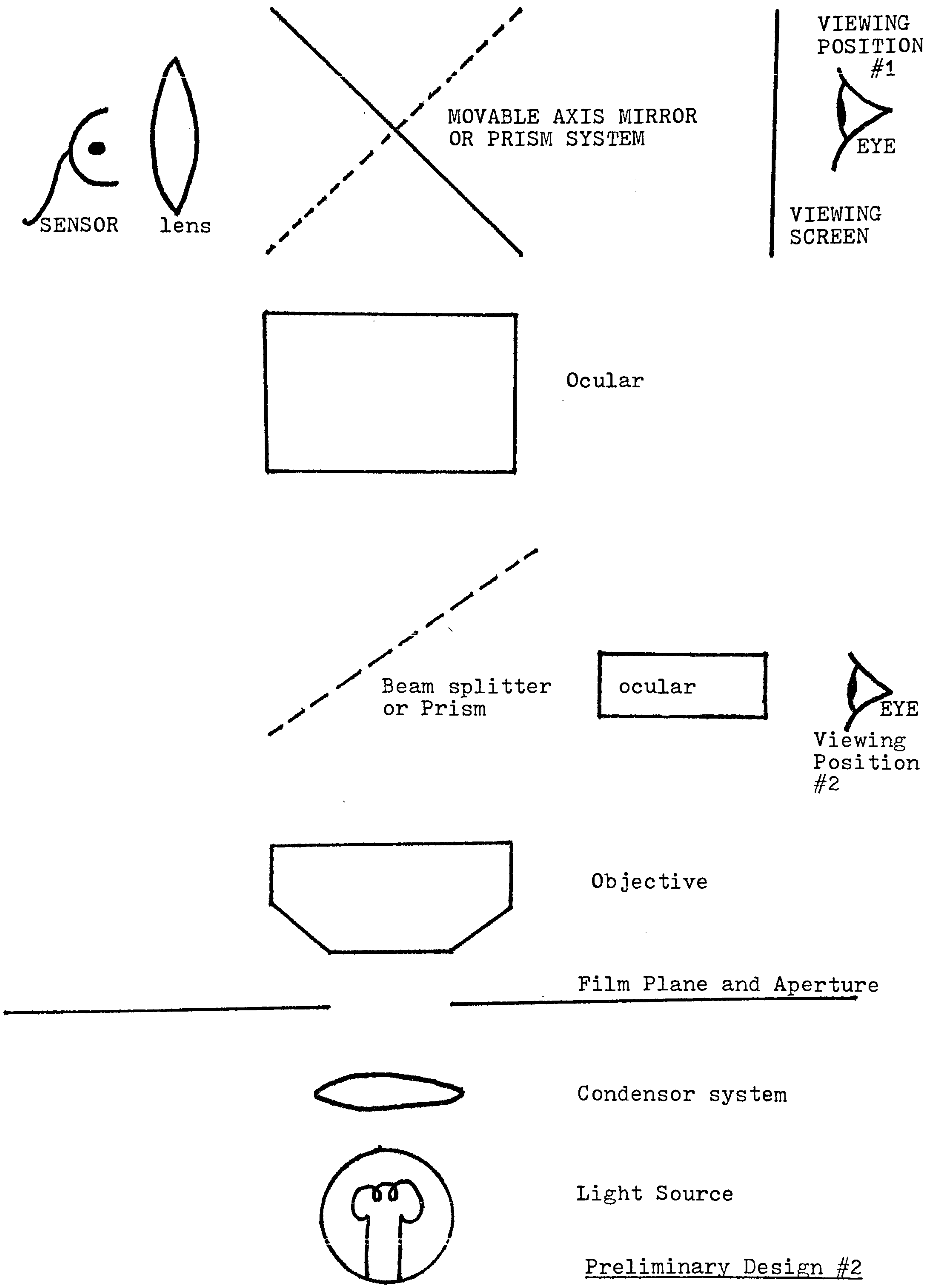
Mrs. Joyce E. Biss, University of Rochester

Appendix A

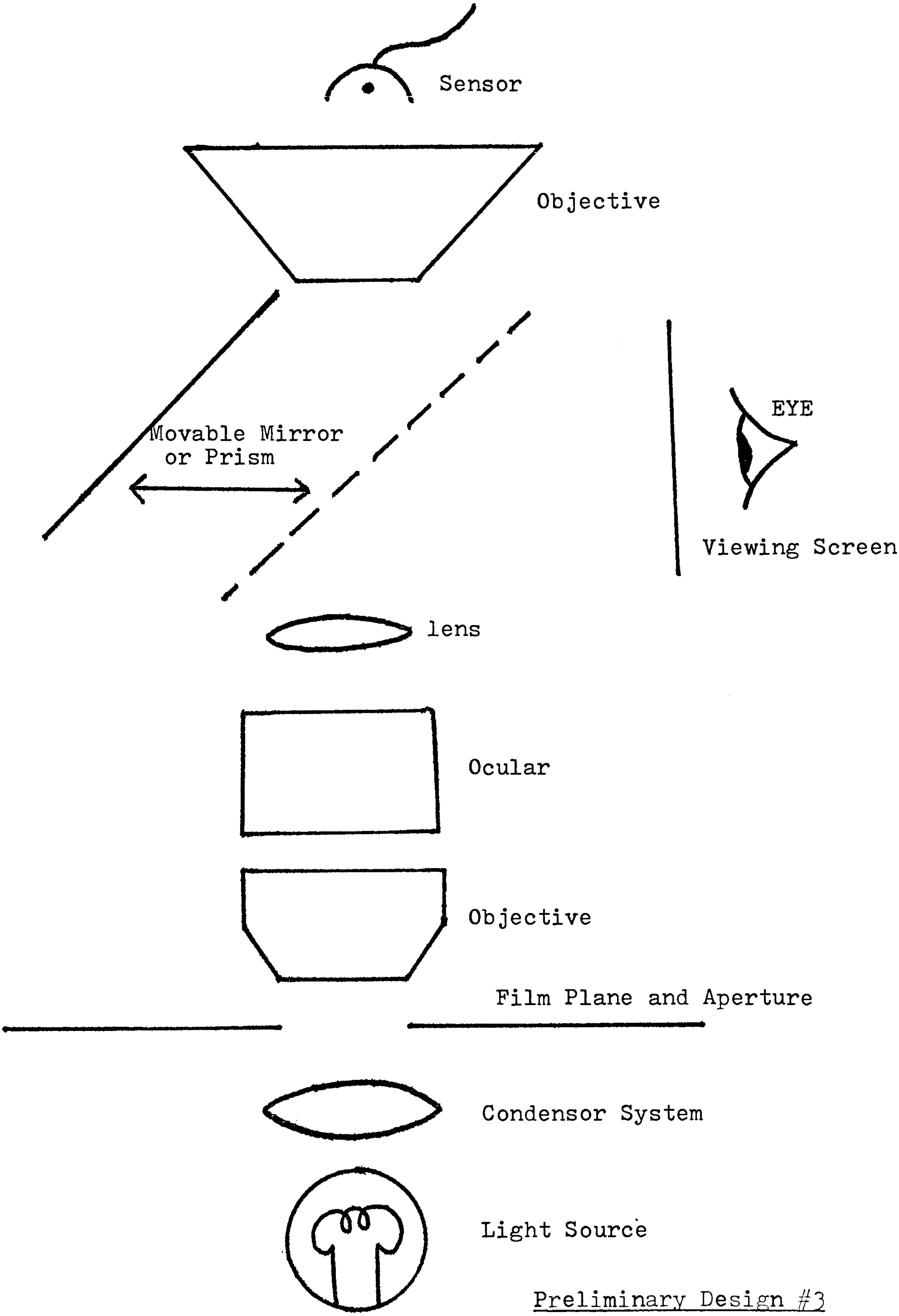
Optical Designs



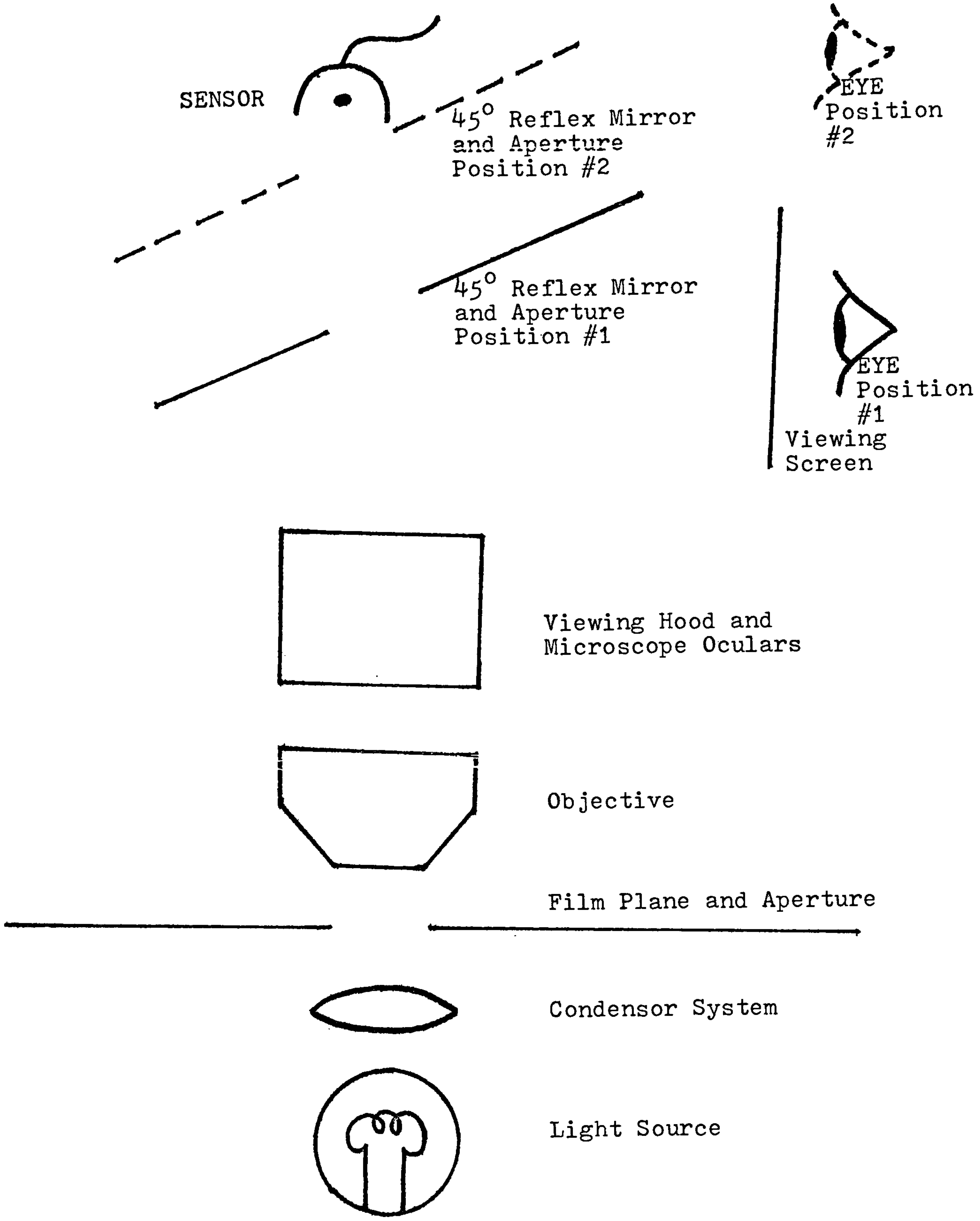
Preliminary Design #1



Preliminary Design #2



Preliminary Design #3



Final System Designs

Microdensitometer Optical Design

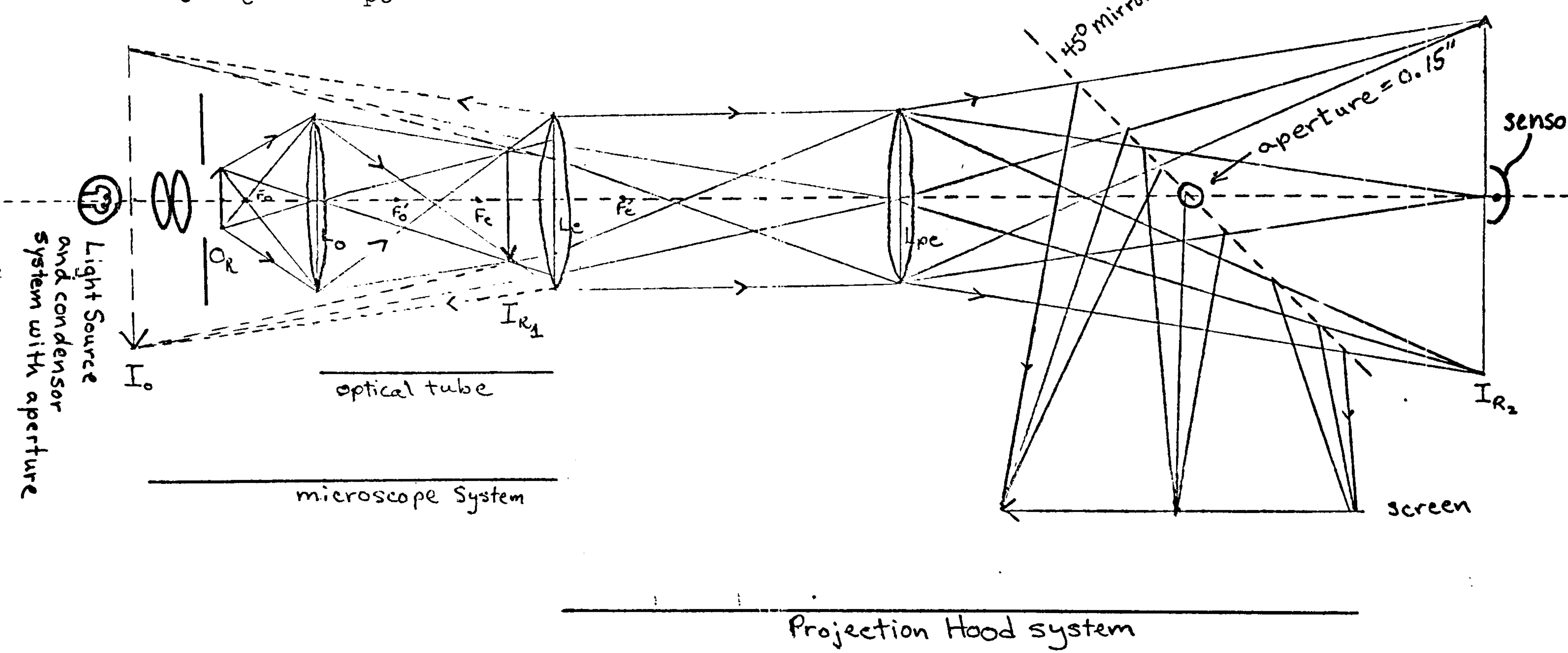
L_o: M_o=10x, F_o=16mm., N.A.=0.25, balcoted, divisible (4x with lower lens off).

L_e: M_e=10x, F_e=25mm, balcoted. L_{pe}: F_{pe}=170mm. System: M_s=68.58x

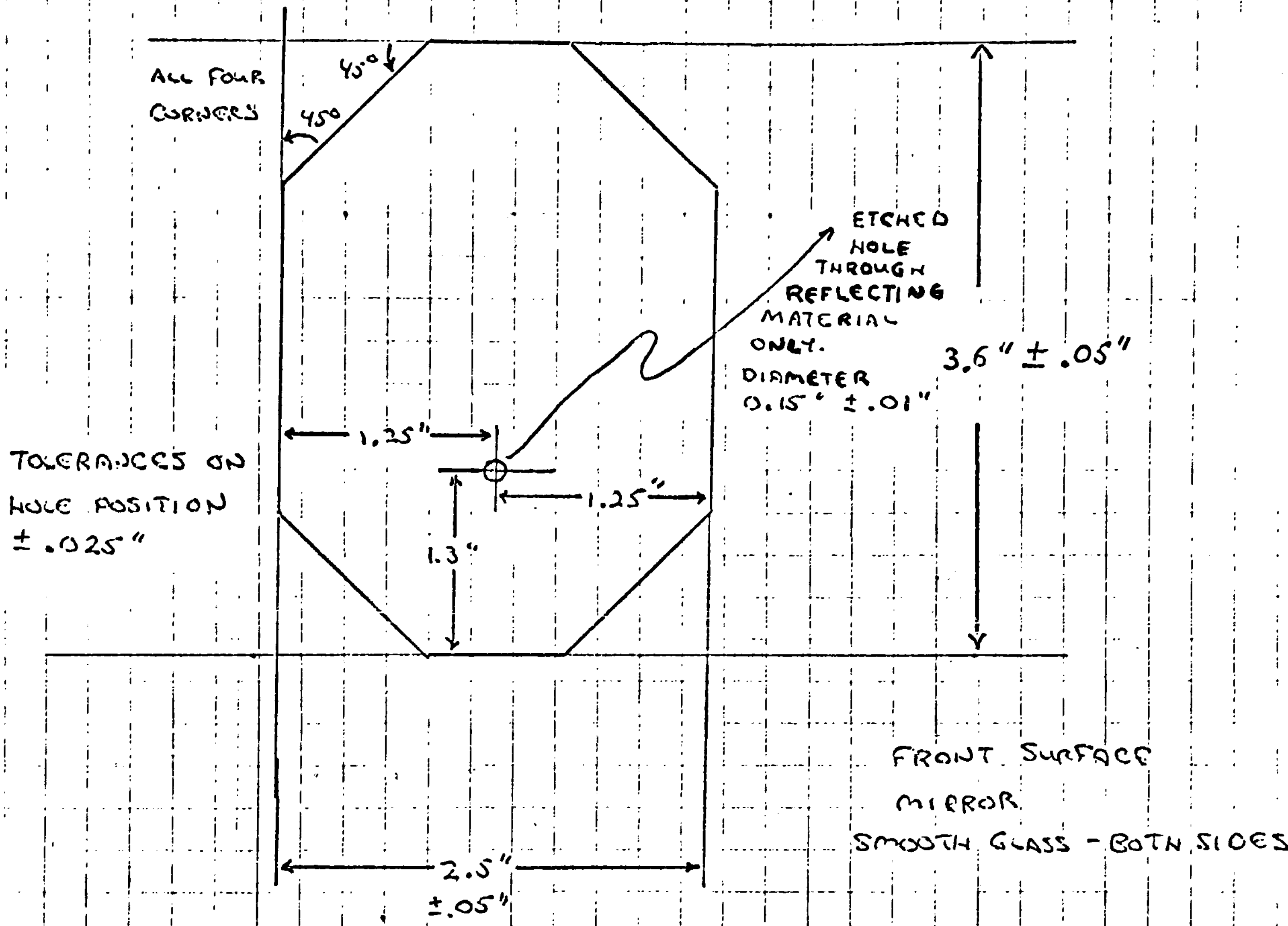
O_r=object, real; I_o=image, imaginary(as viewed); I_{r1}=image, real (as viewed in microscope)

I_{r2}=image, real(projected, as seen in screen)

L_o, L_e, and L_{pe} are all lens systems, factory assembled.

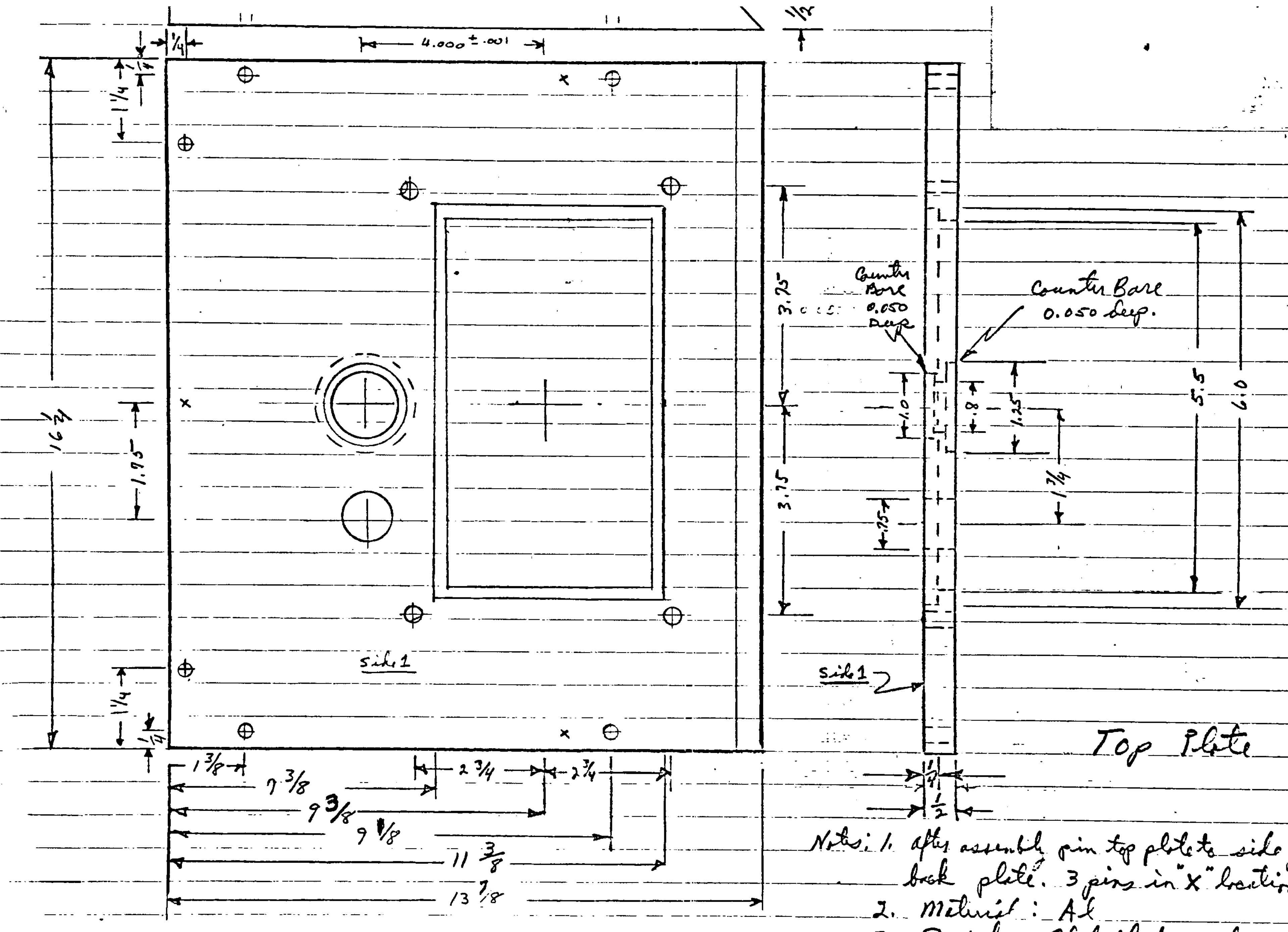


MIRROR Design



Appendix B

Case Design



Top Plate

Notes: 1. After assembly pin top plate to side plate + back plate. 3 pins in "X" locations

2. Material: Al

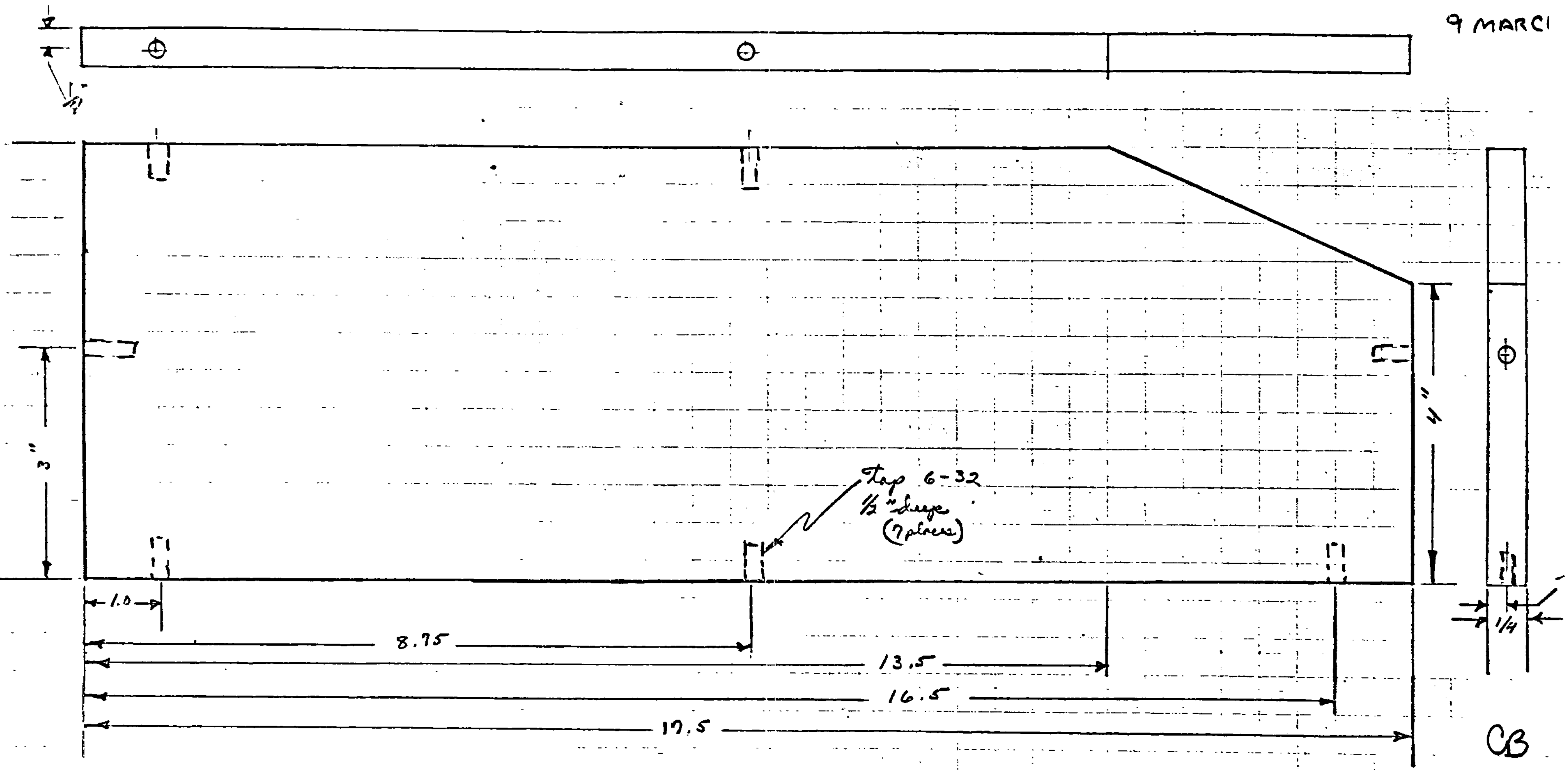
3. Finish: Flat Black Anodize

4. 1 part required.

CB

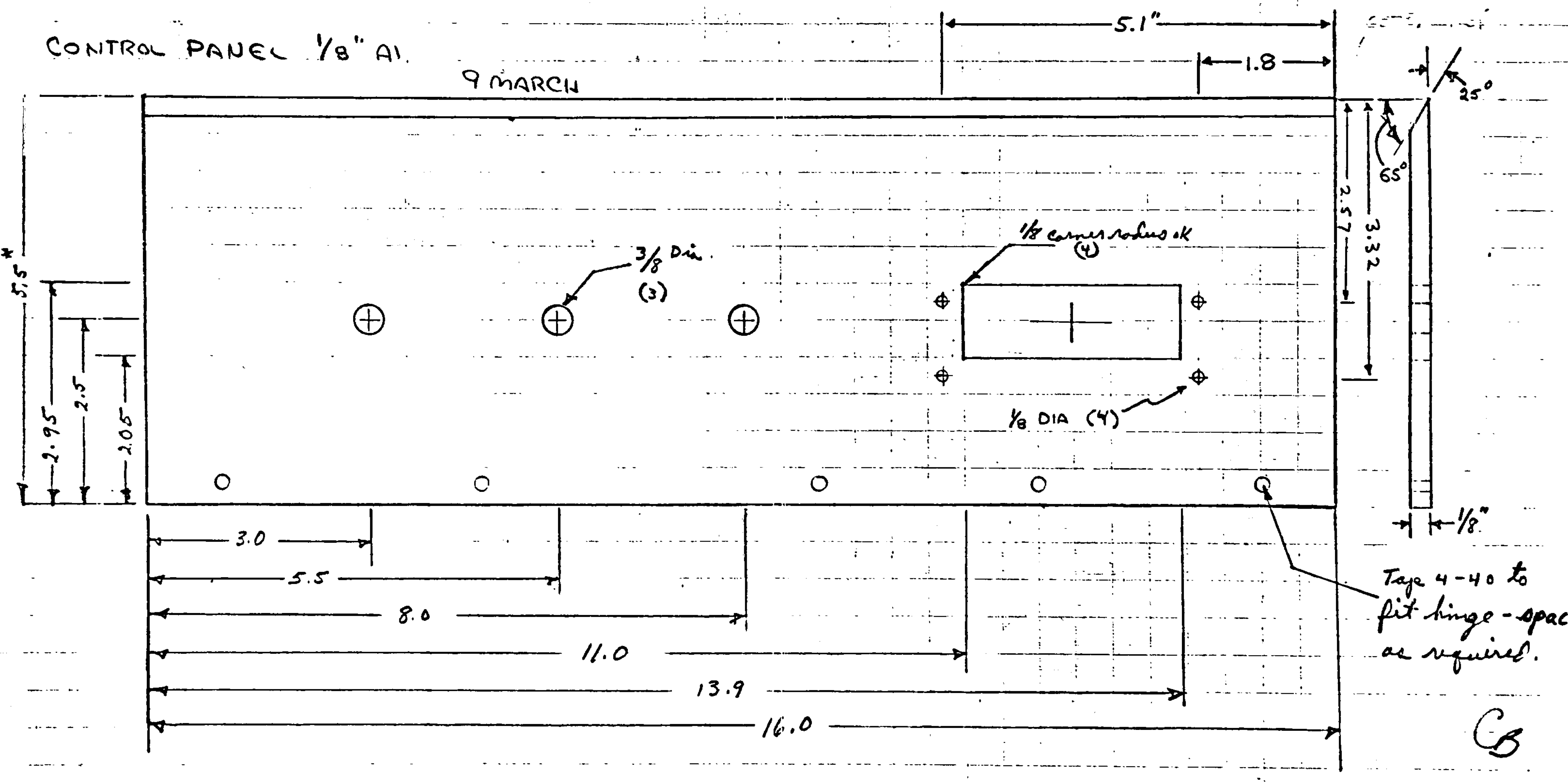
NO SCALE on this Dwg.

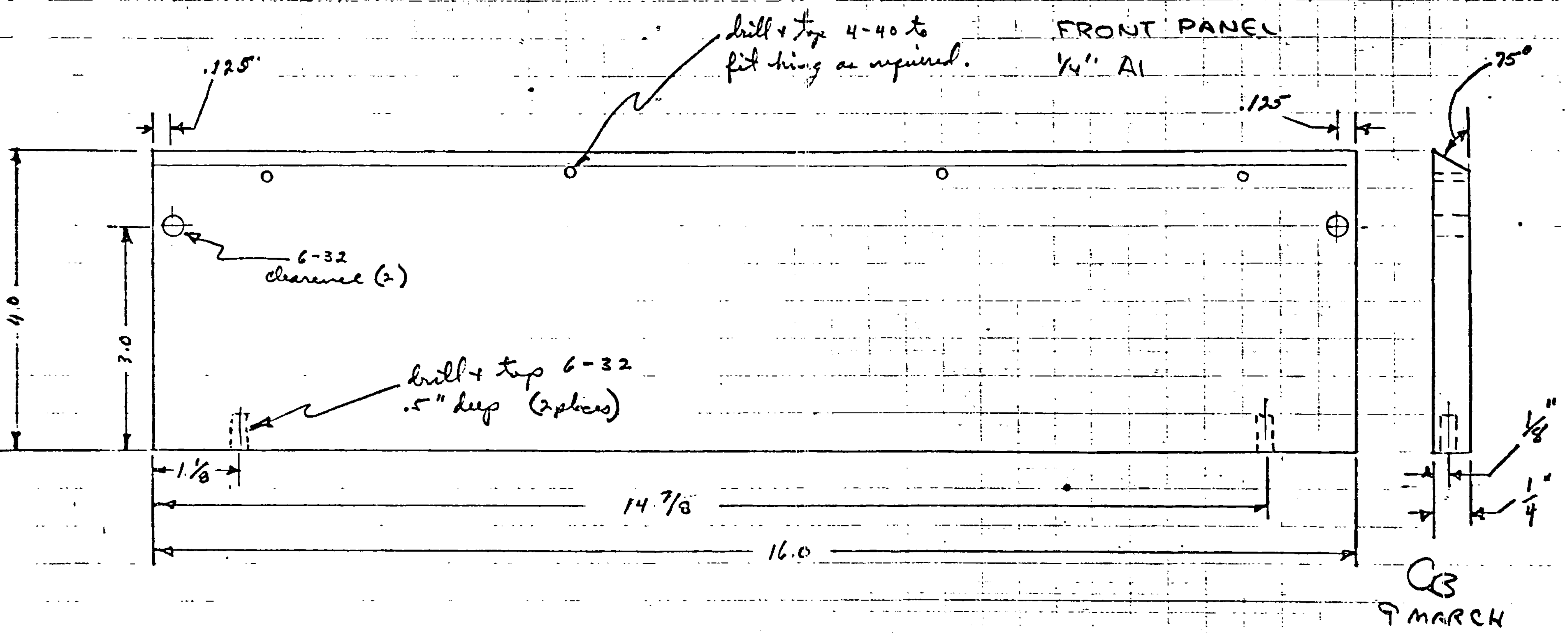
SIDE PANEL 1/4" Al.
9 MARCH



CONTROL PANEL 1/8" Al.

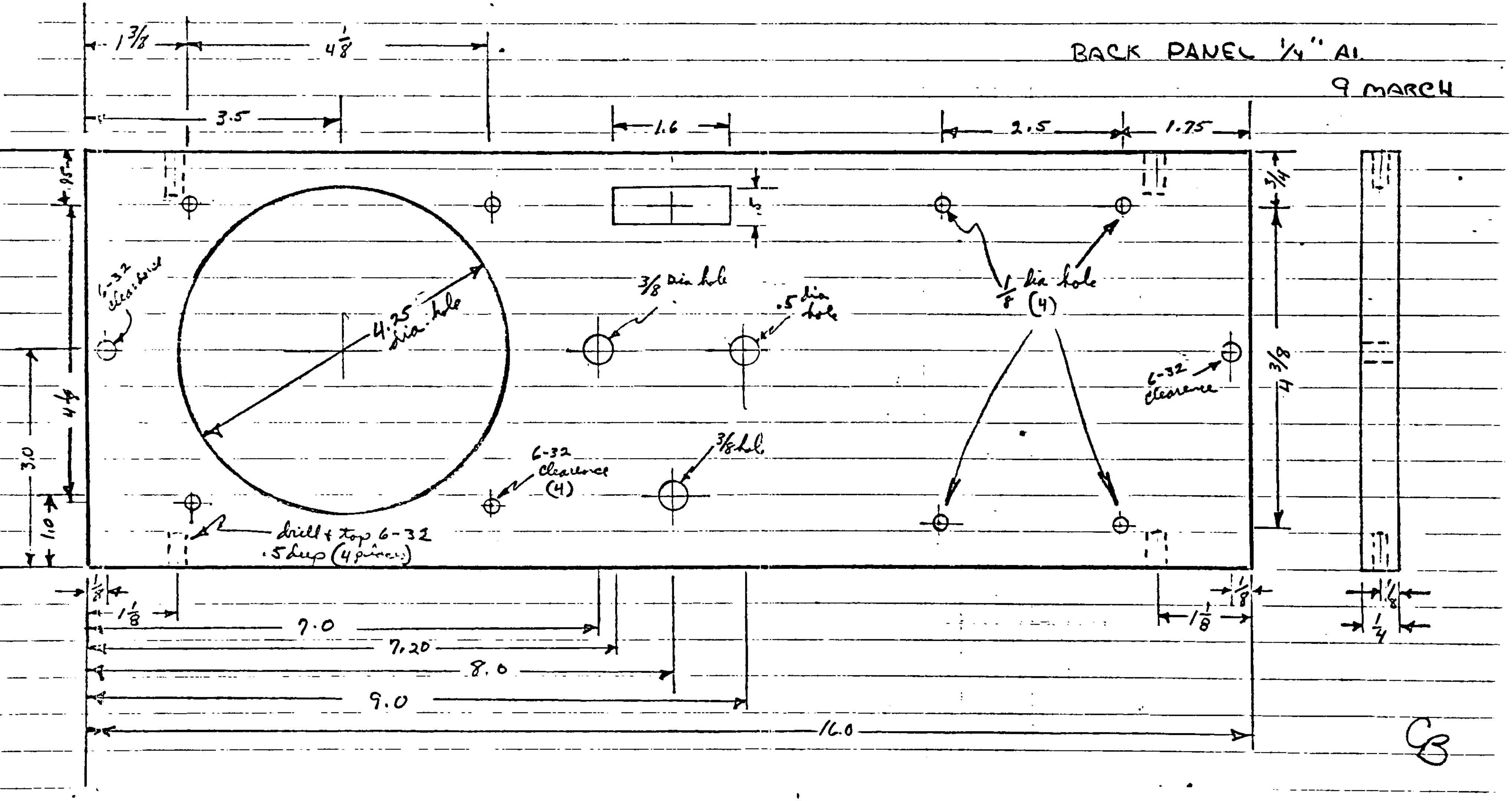
9 MARCH

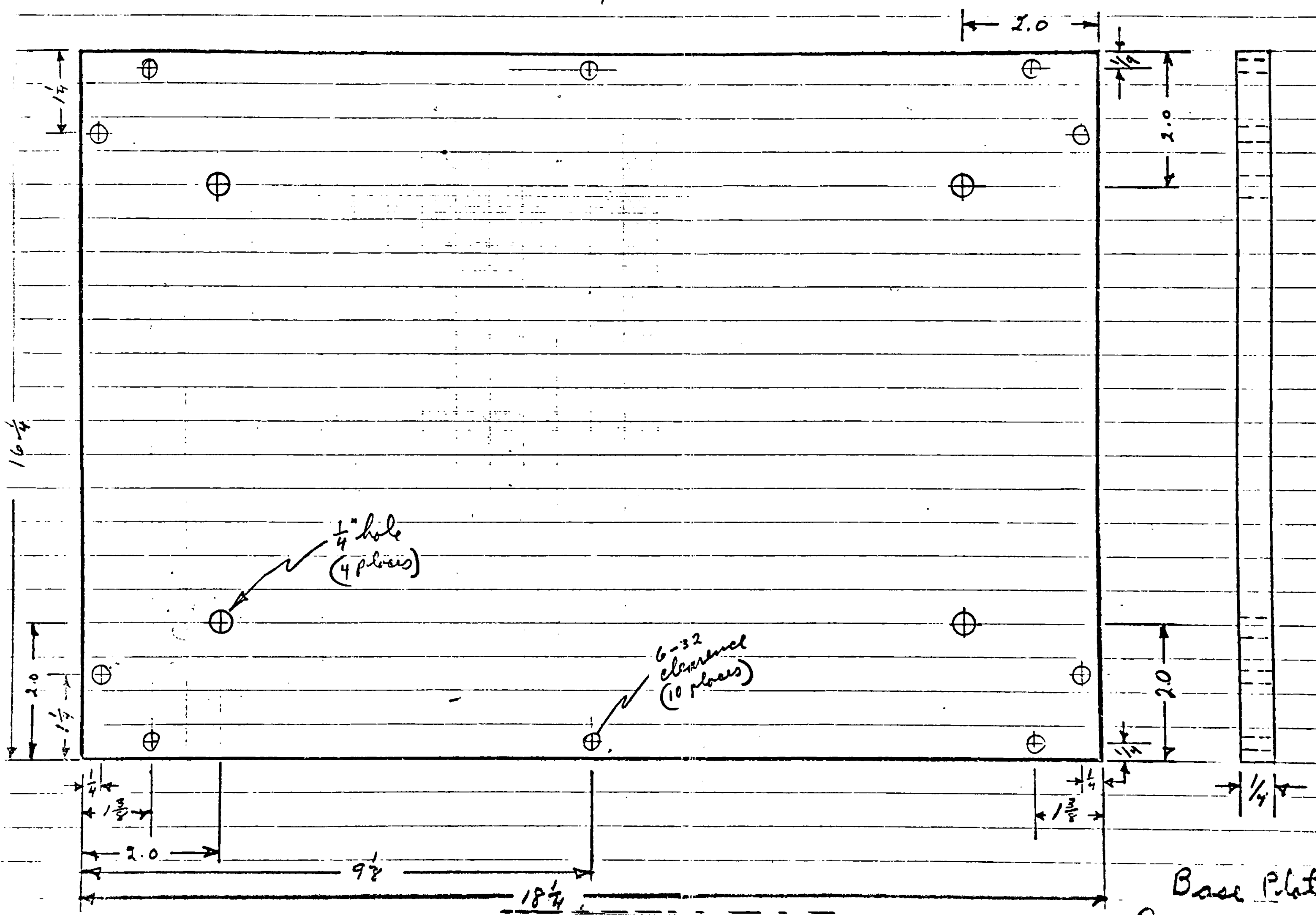



FRONT PANEL
1/4" Al
drill + tap 4-40 to
fit hinge as required.
6-32
clearance (2)
drill + tap 6-32
.5" deep (2 places)
.125
.125
75°
1/8"
1/4"
4.0
3.0
1 1/8
14 7/8
16.0
CB
9 MARCH

BACK PANEL 1/4" Al

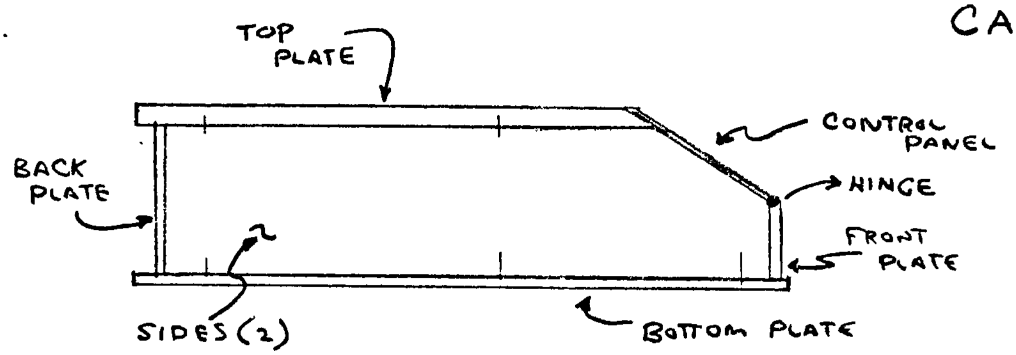
9 MARCH



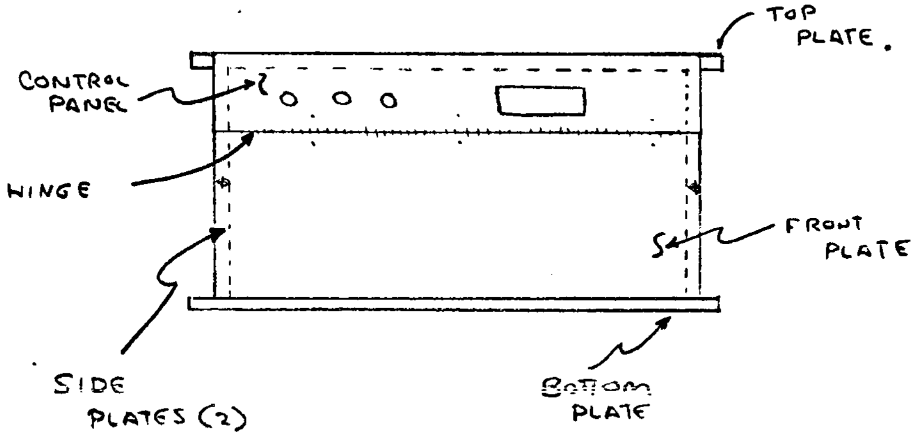


Base Plate 1/4" Al

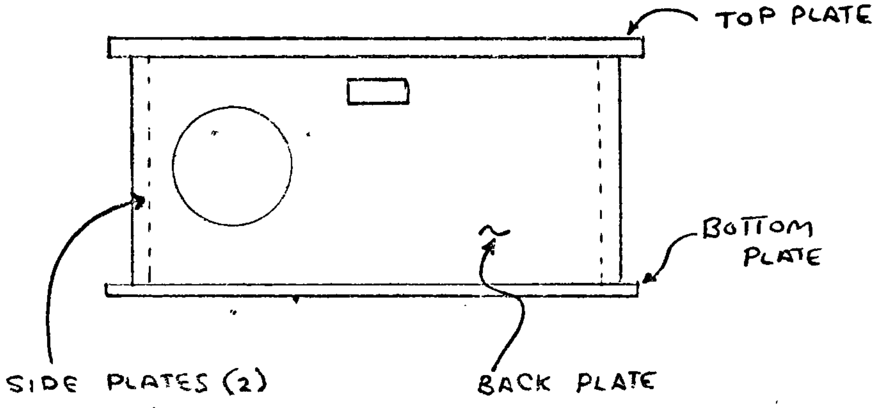
CASE ASSEMBLY



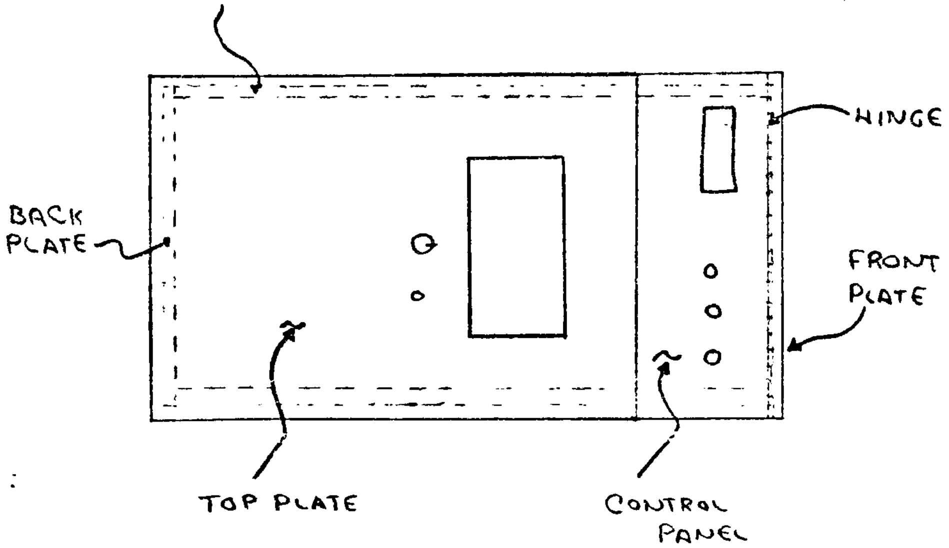
SIDE VIEW



FRONT VIEW



BACK VIEW



TOP VIEW

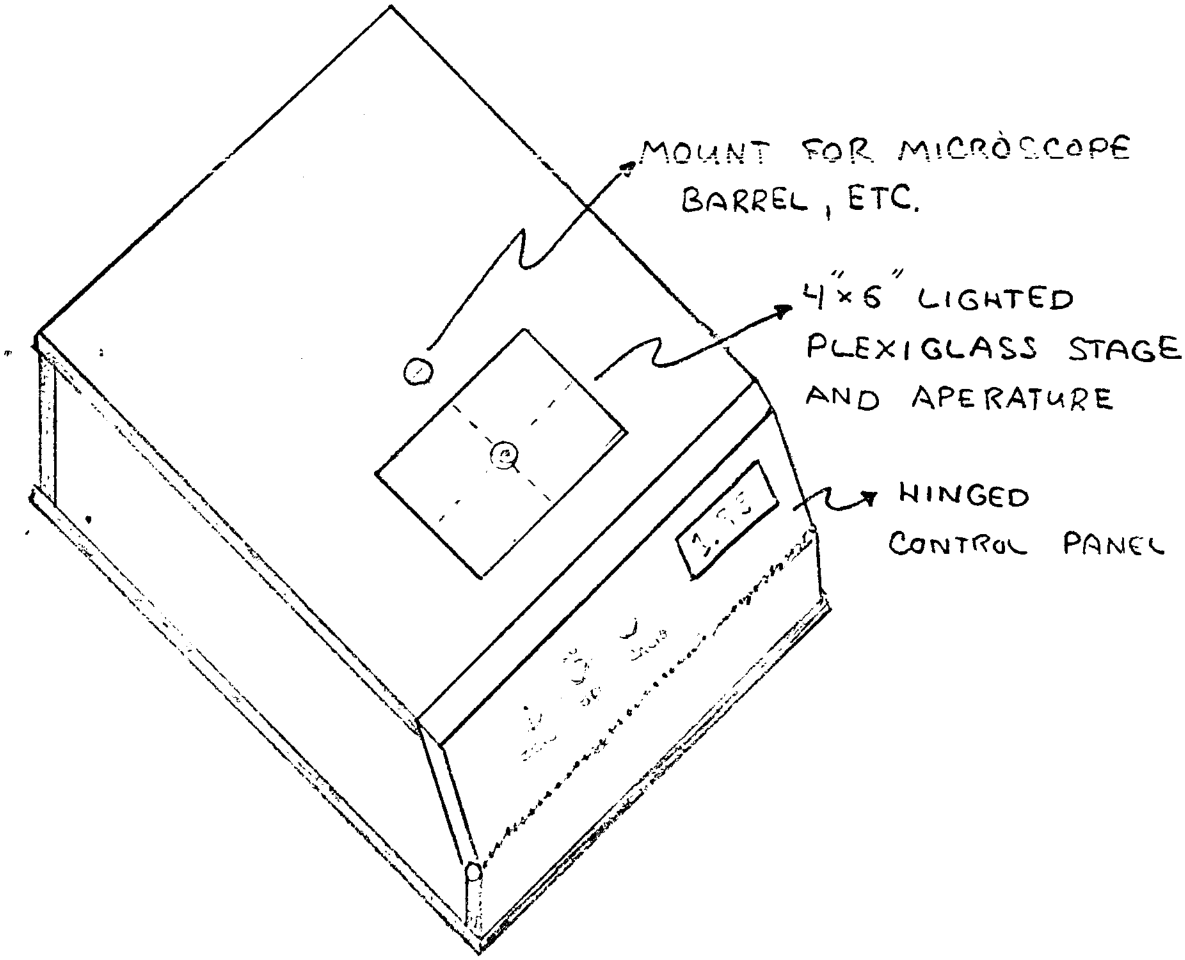
"CASE DESIGN SKETCH"

LIGHT BOX AND ELECTRONIC COMPONENT CHASSIS W/O MICROSCOPE OPTICS, REFLEX HOOD, AND PROBE.

CASE ALL BLACK ANODIZED W/EXCEPTION OF CONTROL PANEL WHICH IS CLEAR ANODIZED.

ALL PIECES OF ALUMINUM

CONTROL PANEL	1/8"	THICKNESS
TOP PLATE	1/2"	"
SIDES, ENDS, + BOTTOM	1/4"	"



2 MARCH '74

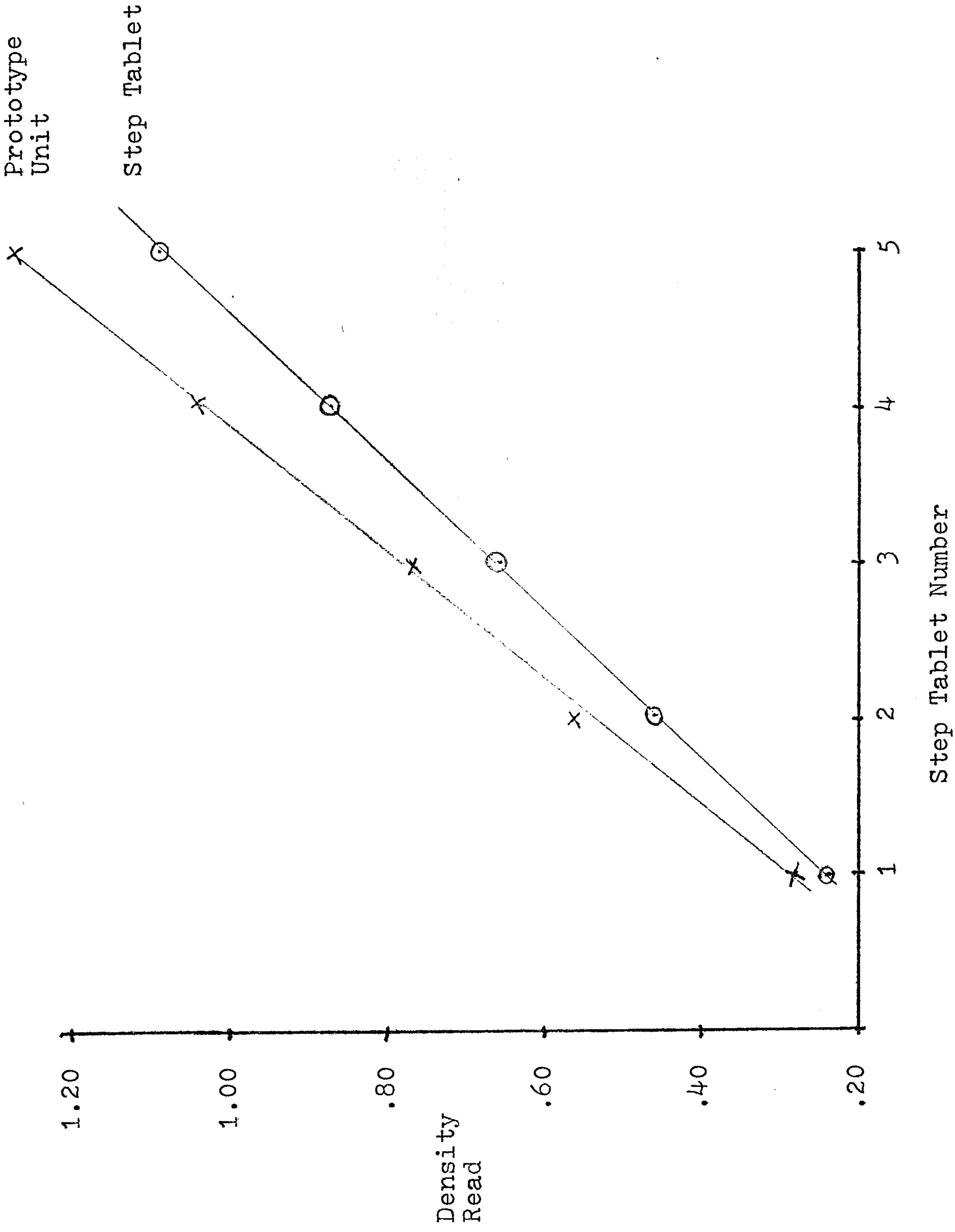
C.C. Bess

Appendix C

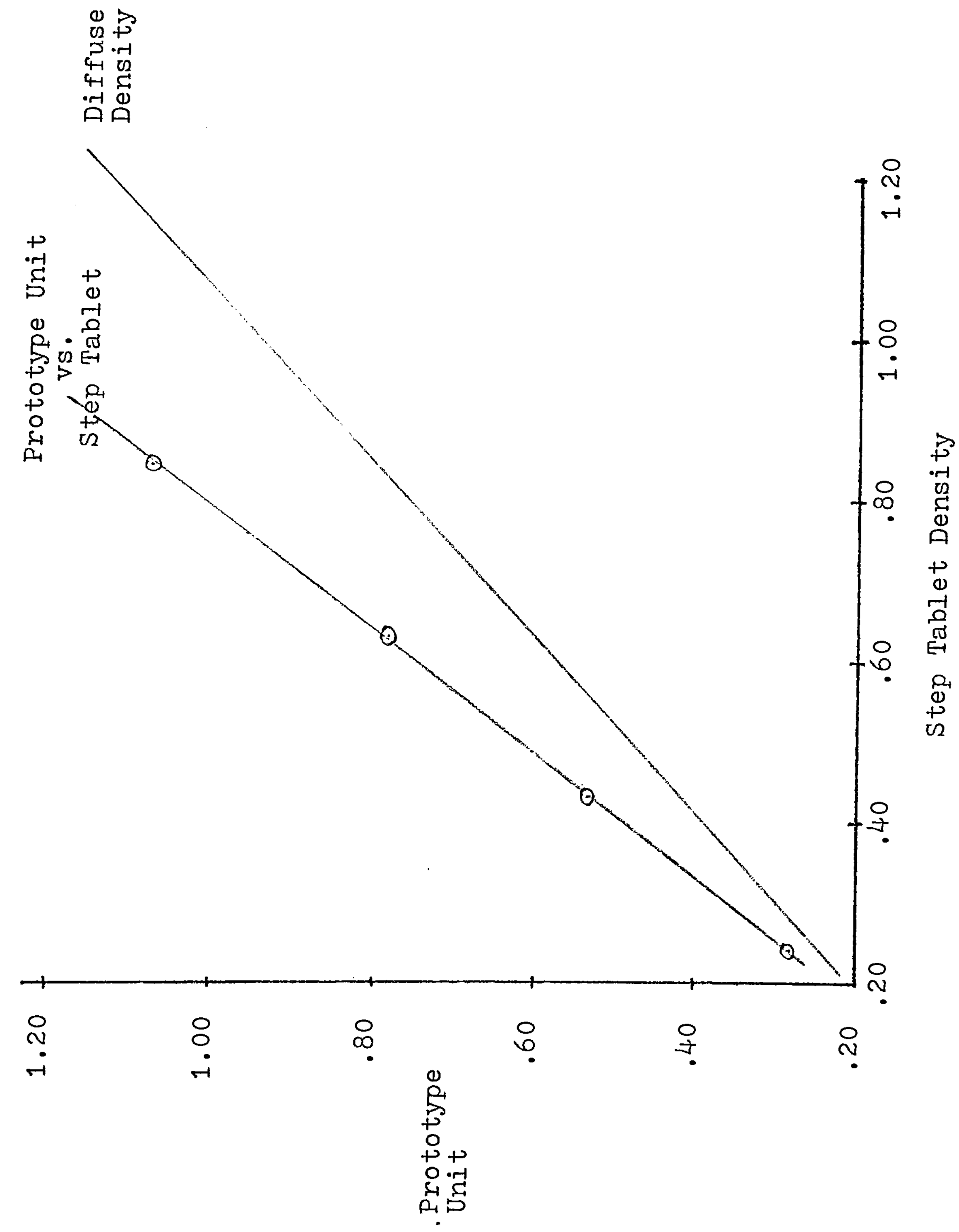
Density Data and Graphs

Appendix C

Density Read vs. Step Number



Prototype Unit Density vs. Step Tablet Density



Step #	Tablet Density	Prototype Density
1	0.24	0.28
2	0.43	0.53
3	0.63	0.78
4	0.84	1.04
5	1.04	1.28

Density Values indicated as "Tablet Density" are the density values printed on the step tablet as determined by the Sargent-Welch Company.

The above values represent one run of density checks on the prototype. Over a total of five runs there was a varience of $\pm$0.005 density units for each step over the total of five runs.

Appendix D

Suggestions for Future Work

Suggestions for System Redesign or Improvement

Have the electronics for density reading designed specifically for this system. This would be more practical than using existing photometers.

Make the case itself smaller with the viewing hood lower or at an angle to permit easier operator viewing.

Replace the photomultiplier tube with a photosensitive silicon photo-diode, if this is feasible.

In place of an etched mirror, attempts should be made to test the performance of: a hinged mirror, a beam splitter, or a mirror with the aperature etched completely through the glass, instead of just in the reflective coating.

A longer throat and optics mounting design should be considered. The longer throat would allow for larger samples to be read. The possiblity of a two point mount instead of the single point mount used, would strenghten this system and insure against any possible vibration.

Incorporate a drop down cone which has a plexiglass piece with a small aperature in it, to hold the sample as flat as possible.

Incorporate an X-Y Coordinate scale on the projection screen. By using a micrometric scale or other calibration devise, the screen can be calibrated to measure dot size. Also, a method to move the film across the stage in both the X and Y direction should be added to permit easy lining up of the image. Position of the dot (aperture in the mirror) would be the center of the X-Y scale.

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F.A. Cicha, Marketing Manager, Photographic Sciences Corporation, Webster, New York 14580

H.N. Todd, Professor, Rochester Institute of Technology, Rochester, New York 14623

B. Archer, Director, Graphic Arts Research Center, Rochester Institute of Technology, Rochester, New York, 14623